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An Investigation of Traffic Characteristics and Their Effects on Driver Behaviors in Intersection Crossing-Path Maneuvers

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Abstract

Vehicular safety research activities have been active in recent years with a focus on the developments of driver assistance systems. Intersection collision is a primary category of roadway safety concerns that can benefit from vehicle-based as well as infrastructure-based solutions. This paper provides a discussion of traffic characteristics and their effects on driver behaviors in intersection across-path turning scenarios. The techniques of data analysis explained in this paper rely on the use of data from field observation. The results offer some insight on the understanding of driver risk-taking behaviors in specific maneuvers. Through the investigation of traffic data and the associated analysis, the criteria for selecting warning threshold for driver assistance can be properly defined. Furthermore, the necessity of adjusting warning timing and criteria under different traffic conditions is explored. In all, the work reported in the paper represents a first step in establishing the guidelines for eventual deployment of suggested intersection safety systems.

Key Words — Driver Assistance Systems, Intersection Collision Avoidance, Intersection Turning Maneuvers

1. Background

Intersection safety is a primary traffic concern, especially in the urban regions. In the last few years, a number of research projects are initiated to pursue safety countermeasures for the reduction of crashes at intersections [1-6]. For example, the INTERSAFE project carried out within the European Community 6th Framework program was set out to develop intersection safety systems that can provide accurate localization of the driver's vehicle and path prediction of other road users. Combining this with signal status communication, it will be possible to warn the driver of potentially hazardous situations. As another example, the Japanese government and industrial partners in 2006 are beginning to test the Driving Safety Support Systems (DSSS), which is a system that uses two-way communication devices set up above busy roadways that tells drivers of things such as pedestrians crossing or upcoming merging traffic. In addition, a major project sponsored by US DOT for intersection safety, Cooperative Intersection Collision Avoidance Systems (CICAS), is also underway [7] with multiple industrial and academia participants.

One major trend in these research projects places emphasis on cooperative vehicles and roadways. The operational concept is best illustrated in the US Vehicle Infrastructure Integration (VII) project [8], in which Dedicated Short-Range Communication (DSRC) 5.9 GHz radio is to be used for traffic management and safety applications. Also, the EU-supported Cooperative Vehicle-Infrastructure Systems (CVIS) [9] is developing the core technologies to allow every vehicle to communicate directly with the nearby road infrastructure and with other vehicles in the vicinity. The candidate systems rely on short-to-medium range communications media, such as mobile Wi-Fi, 2G/3G cellular radio, infrared and DSRC. Similarly, a consortium in Japan is strategizing for the progress of Cooperative Vehicle Highway Systems for traffic management and safety purposes. [10].

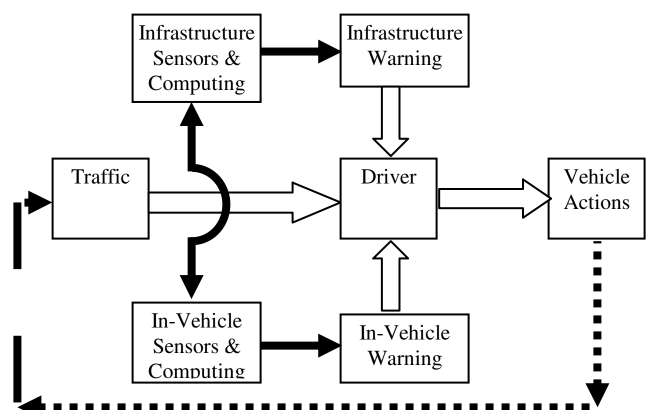

Figure 1 Interaction and Information Flow In a Intersection Driver Assistance System

The intersection safety systems rely on the combination of sensing, computing, and communication technologies to offer timely alerts to drivers who may not realize the eminent danger in traffic. The alert messages are conveyed to drivers through infrastructure-mounted signs or through on-board warning devices. A schematic information flow chart is illustrated in Figure 1. The work reported herein is a step toward establishing the guidelines for the eventual deployment, which allow the selection of implementation options to suit the specific attributes of an intersection and the associated traffic phenomena.

2. Relevance of Traffic Characteristics to Intersection Conflicts

For the purpose of discussions in this paper, it is more fitting and worthy to examine the behavioral drivers aggregately, but not individually. In other words, more emphases will be placed on the overall deviation exhibited by a group of drivers rather than the specific determination of an individual driver. The reason for this approach is based on several considerations. First, the alert issued to drivers in the proposal driver-assistance systems may be in the form of a roadside display or an in-vehicle driver interface, or a combination of both. The warning message must be unambiguous and not contradictory, especially when both roadside and onboard interfaces are utilized. Furthermore, in order to convey a consistent message to all drivers it will be necessary to choose a common risk threshold that is safe for operations and acceptable by most drivers. Moreover, while preparing for field operational tests, it is appropriate to understand the aggregate behaviors at a specific intersection.

Based on the considerations above, a central question in the provision of driver assistance in intersection crossing-path maneuvers is whether uniform warning criteria can be adopted for different locations and traffic conditions. For example, do drivers have a tendency to become more aggressive or more cautious under heavier traffic or faster opposing traffic? Should different warning thresholds be adopted at different intersections? If so, can the primary attributes be identified and the correlations quantified? The work reported in this paper was an attempt to answer some of these questions. Several categories are considered and elaborated below:

(1) Traffic Control Device Related
At a signalized intersection, priority is given to certain traffic directions in turns to ensure the safety of traffic flows. However, some complicating factors can render signalized intersections into problematic locations. First, drivers do not necessarily observe and obey control signals. Secondly, traffic hazards can still arise due to erroneous judgment or inattention. Furthermore, signal control imposes waiting periods and potentially lead to impatient or aggressive driver behaviors that contribute to safety problems.

On the other hand, stop signs are often used at non-signalized intersections where priority preference is given to one primary direction. In these cases, traffic entering from secondary directions must yield to the primary direction. Driver misjudgment and incapability to observe a proper gap are usually the causes for collisions, especially in rural expressways [11].

(2) Signal phase length and timing
Due to operation considerations, the cycle length and relative timing of signal phases are often tuned to achieve the maximum efficiency. The primary leg of an intersection typically takes up a larger portion of the signal cycle. In addition, there are practices of flexible signal timing where different phases is controlled to minimize the waiting time of standing traffic and to expedite the flow resumption on the major traffic directions. Under various operational policies and signal control techniques, traffic patterns can be meaningfully different.

For example, if vehicles waiting for permissive turns must wait for an excessively long period of time, then it may induce more aggressive driver actions that are not normally taken under more relaxed traffic conditions. For another example, if the opposing traffic contains a densely followed platoon of vehicles with minimal headways between them it may lead to riskier decisions by drivers. As another example, at an intersection with a short green phase, permissive turns can only be made after the end of the green and into the amber or the red phases, as there is virtually no gap available for a safe maneuver. In summary, the relative allocation of signal phase timing can have a meaningful impact on driver behaviors.

(3) Traffic Speed and Volume
Previous research suggested that driver decisions of turning maneuvers at intersections are based on a combination of target distance to intersection and time to intersection [12-13]. Recent field work also supported the notion that target vehicle arrival time is a good measure of gap acceptance [14-15]. Since the arrival time of an oncoming vehicle is perceived by drivers by observing target distance and speed, it will be helpful to explore whether driver perception errors are prone to occur for targets in a certain speed range.

Another traffic factor is the volume of opposing traffic. The direct impact of heavy volume is the reduction of average gap between vehicles. Besides, the presence of heavy traffic can be visually more threatening thus causing differences in driver decisions. Similarly, the simultaneous presence of targets in multiple lanes may present visual threats to drivers.

Besides the three categories of traffic characteristics above, there are additional situations that may have significant effects on incidental driver decisions. Certain factors are location specific, while others are universal. For example, the frequent presence of vulnerable road users such as pedestrians and bicyclists can complicate the interactions of traffic flows. Some factors not covered in this paper will be investigated in future work.

3. A Comparison of Traffic Data

In recent years, a methodology was developed at PATH to rely on field observations to facilitate the understanding of driving behaviors in intersection turning scenarios [14-15]. The data collection was conducted with a roadside mobile station with radar, video, and data acquisition equipment.

Figure 2 depicts an exemplar setup at an intersection. More detailed descriptions of the field observation setup can be found in previous publications [15]. A mobile platform, consisting primarily of a radar sensor and a data acquisition computer, was deployed at selected intersections. The radar was oriented to capture the oncoming traffic, as indicated by the blue triangle that represents the coverage area of the radar.

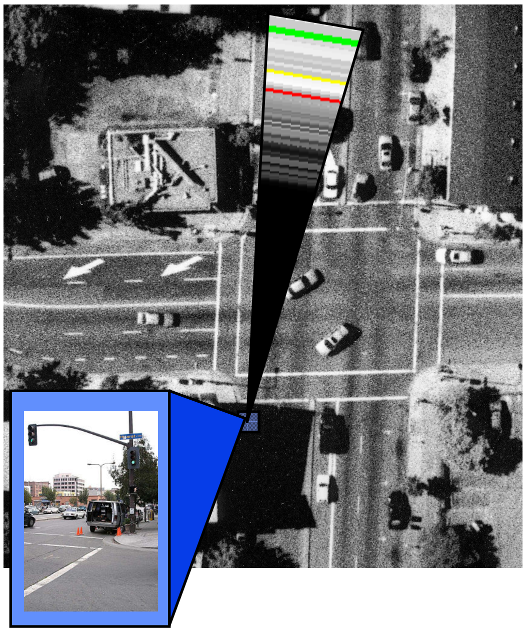

Figure 2 Schematic Diagram of Data Collection Setup

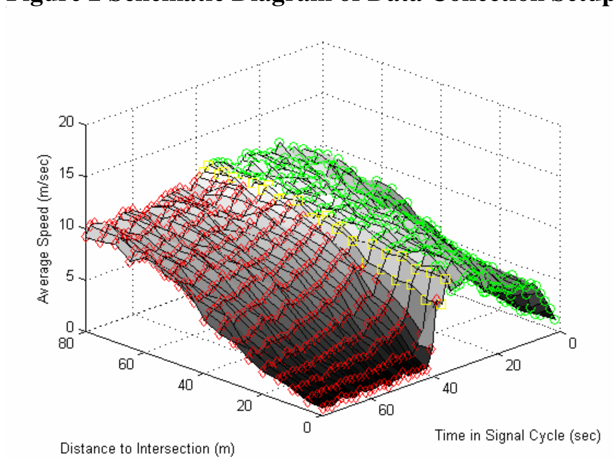

Figure 3 Distribution of Average Approaching Traffic Speed within a Signal Cycle at Intersection A

Figure 3 is a graph showing the average traffic speed of approaching traffic detected by the radar at Intersection A. One horizontal axis is time in the signal cycle, in which the 75-second cycle is divided into 34.1, 3.3, and 37.6 seconds of green, amber, and red phases respectively. The surface chart is marked by color line plots to indicate the corresponding signal phase. The other horizontal axis is the distance from the stop line (the leading edge of pedestrian crosswalk in this case) at the intersection. There is an obvious transition from green to amber to red, as well as a change in speed at the beginning of green. Also, the further away from the intersection, the effect due to the signal phase is less on the average speed.

Figure 4 is a graph showing the distribution of speed in the amber phase. The mean value and plus/minus one standard deviation of target speed are indicated for every 5-meter section. The the speed differential for individual vehicles diverge as they get closer to the intersection in the amber phase as some drivers choose to proceed through the intersection while others stop for the signal.

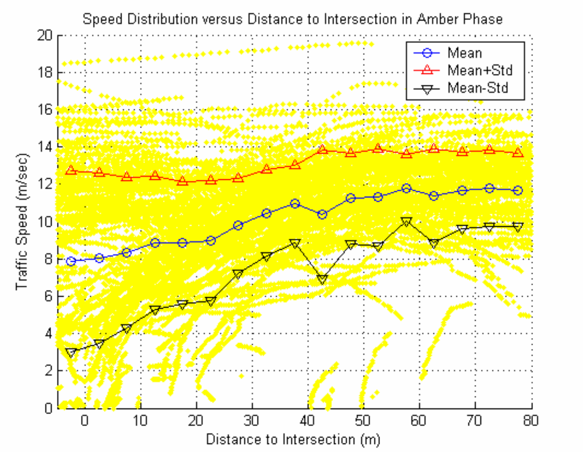

Figure 4 Distribution of POV Approaching Speed Traffic in Amber Phase at Intersection A

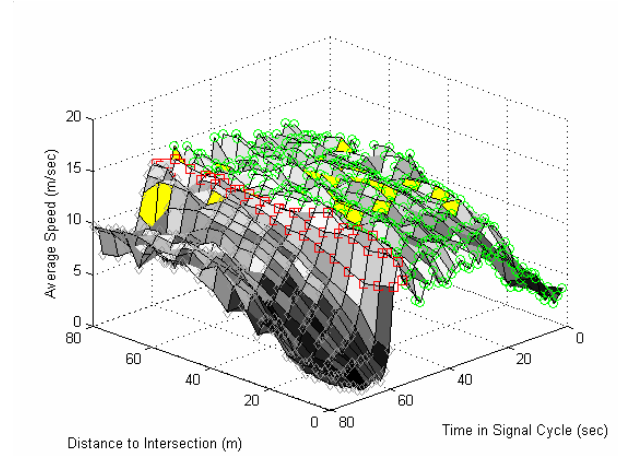

Figure 5 Distribution of Average Approaching Speed of POV Traffic within a Signal Cycle at Intersection B

Figure 5 is a graph similar to Figure 3 with data for Site B. There are some notable differences in traffic patterns. First, the signal cycle for B is 80-second long with about two-thirds of time given to the direction of the approaching traffic. The traffic is moving along a major local corridor with consistently high volume of traffic, roughly 400-600 vehicles per lane per hour, of traffic. Also, the cross street signal is controlled by actuation so that the length of the green phase is not constant for the primary traffic direction and it varies between 55 to 65 seconds. As a result, the first 10-second data in the green phase include a mixture of moving targets under green and stopped vehicles under the red signal.

The prevalent traffic speed is higher (near 15 m/sec) at B when compared to Intersection A (about 10 m/sec). In addition, the average speed in the red phase at a distance (50-80 m) in Figure 4 is relatively slower than that in the green phase. This is different from the data for Intersection A in Figure 2, where the average speed for traffic at a remote distance is about the same for different phases. This pattern is a geometric feature of Intersection B, where another upstream intersection is located at about 100 meters from B. Most targets in the range during this period of the red phase come mostly from those vehicles that turn into the main corridor from the cross street at the upstream intersection. Therefore, these vehicles possess a lower speed on average.

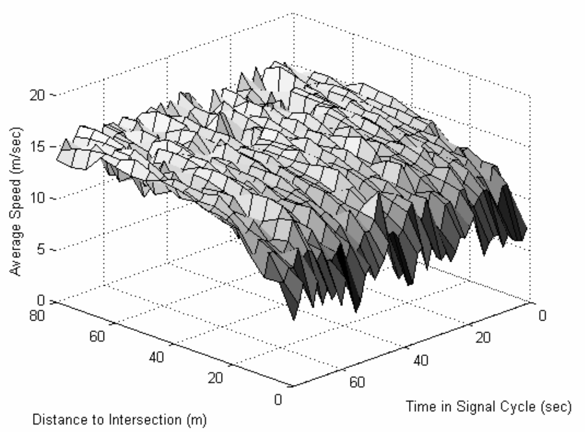

Figure 6 Distribution of Average Approaching Speed of POV Traffic at Non-signalized Intersection C

In contrast, Figure 6 shows the data from a non-signalized intersection. The cross traffic is controlled by a stop sign. The traffic speed is slightly above 15 m/sec on average, the highest among the three locations. The traffic slows down as they approach the conflict zone. The slowdown was mostly a result of some vehicles decelerating to make a right turn or slowing down due to the presence of crossing traffic. As depicted by Figures 3-6 above, there are noticeable differences in the traffic patterns due to traffic control, speed, and signal cycle. A methodology of evaluating traffic effects will be presented in the next section.

4. Evaluation of Intersection Conflicts in Left-Turn Across-Path Opposite-Direction Scenarios

It was estimated from a national crash database in US that crossing-path collisions represent 25% of all US police reported crashes, and almost 45% of all crashes at intersections [16]. One identified high-risk scenario is the so-called Left-Turn Across-Path Opposite-Direction (LTAP-OD) situation, which is depicted in Figure 7. The LTAP-OD conflict occurs when a subject vehicle (SV), while making a left turn, encounters a threat presented by an approaching principal other vehicle (POV). POV refers to the opposing vehicle that is most likely to be in conflict with SV due to its closeness in distance or time.

Two major parameters reflecting driver risk-taking behaviors are defined as follows:

(1) Gap Acceptance

SV drivers typically seek a gap in time or distance to make the permissive turn. The decision time occurs before the driver initiates the turn, either at a stopped position or from a moving position in its approach. The accepted gap is assessed a few seconds prior to the actual turning action. The exact moment of driver decision is difficult to pinpoint, but previous studies suggest that it can be estimated by using the average turning time and a period of perception time [12].

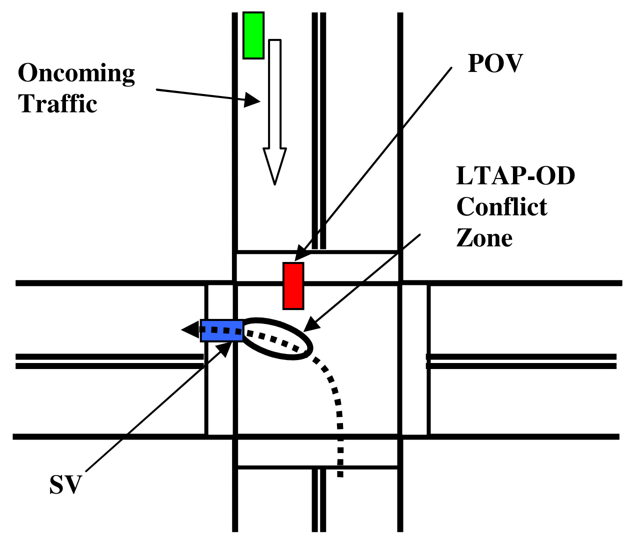

Figure 7 Schematic of LTAP-OD Conflicts

(2) Trailing Buffer

The risk level of a particular LTAP-OD scenario is indicated by the closeness of two vehicles when they are moving toward a potential conflicting position. In a situation as shown by Figure 7, SV has just completed the turning action while the POV is about to enter the conflict zone where a collision might have occurred. The difference in the time of arrival at the point of conflict (POC) is called the trailing buffer. The smaller the trailing buffer, the riskier the situation has been. For example, the green target will have a much longer trailing buffer than the red target in Figure 7.

From the moment of driver decision to the actual crossing of conflict zones, SV and POV motions could be affected by signal phase transition or mutual interaction. Therefore, there could be considerable deviations between the actual trailing buffer and the projected trailing buffer. A distinction should be made in the discussion of such terms.

5. A Sampling of Driver Behavioral Evaluation

Figure 8 is a graph showing the projected arrival of POV in LTAP-OD scenarios for 226 cases. The horizontal axis shows the time before and after the time when SV passes POC. The vertical axis shows the percentage of cases when POV are present when SV is turning. In the graph, the projection of POV arrival is made at -4 to -2 seconds prior to the instant when SV passes POC, and the distribution of arrival times are shown by the three color bars respectively. The three color curves (blue, red, and magenta) in Figure 8 are the cumulative percentage of SV encountering a POV with projected buffers of 0 to 8 seconds.

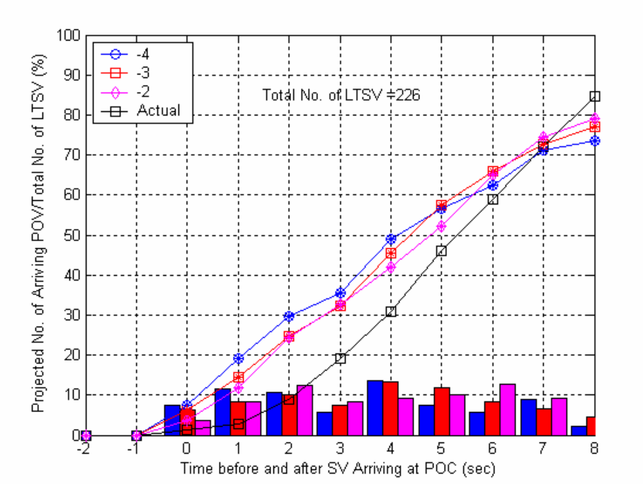

Figure 8 Distribution of Projected POV Arrival Time at Site A

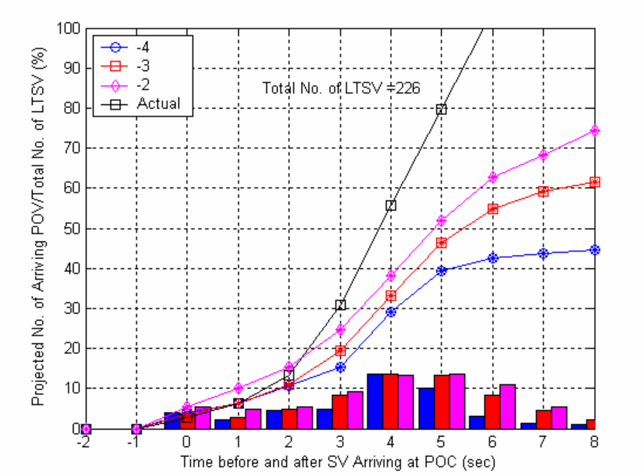

Figure 9 Distribution of Projected POV Arrival Time at Site B

The black-color curve in Figure 8 is the accumulative distribution of actual POV arrivals. It is constructed by counting the number of POV passing POC after the SV leaves POC. A comparison of projected and actual POV arrivals indicates that the actual arrival numbers are smaller than the projected numbers in this case. This is particularly true for the first 5-second period.

Figure 9 is a similar graph corresponding to Site B, where traffic is heavier and moves faster than Intersection A. The data set includes 226 LTAP-OD scenarios. It can be noted that the projected numbers of POV arrival are fewer in B than A, while the actual arrival POV numbers are greater at B than A. This was due to the fact that at Site A the traffic is moving not as fast and POV traffic may choose to slow down in signal transition or when SV is present. At site B, however, the primary corridor traffic tends not to stop as many of them move in platoons. In addition, the actual arrival distribution curve rises much faster than A. This was probably caused by the fact that the POV traffic was heavy on the corridor and targets previously beyond the sensor range arrive later as time goes by.

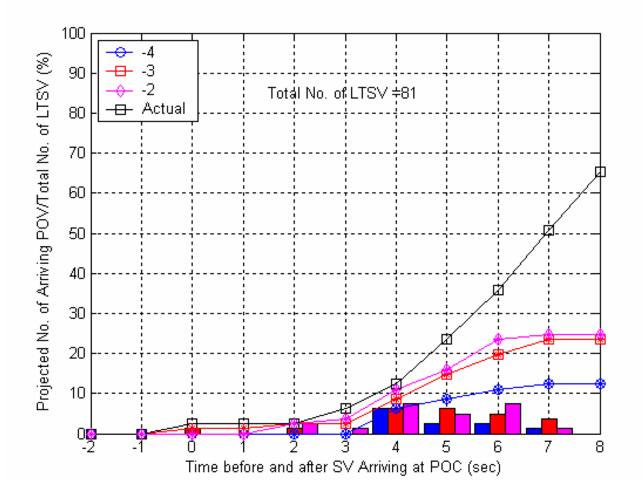

Figure 10 Distribution of Projected POV Arrival Time, Site C

In contrast, Figure 10 offers a similar view of the data for Intersection C for 81 LTAP-OD scenarios. As can be seen in the data, the POV traffic is relatively light and the numbers of Arriving POV are relatively small. SV drivers were quite cautious in selecting a safe gap to turn, as indicated by small numbers of arriving POV at 0-3 seconds in Figure 10.

Limited numbers of samples notwithstanding, it is interesting to note the differences in data from signalized and non-signalized intersections. Signalized intersections could bring about a higher level of traffic interaction thus a higher frequency of hazardous encounters, as illustrated by Figures 8 and 9 versus the data from Site C in Figure 10.

An alternative display of LTAP-OD conflict data is illustrated in Figure 11 for Intersection A. The distance to POC and the projected arrival time to POC are shown in the time window of 4 to 2 seconds prior to the time of SV arrival at POC. Among these targets, those POV that are projected to arrive with a trailing buffer of 2 seconds or less are highlighted with a "*"in the graph. Some observations can be made:

(1) The more threatening POV targets with shorter trailing buffers are those with a shorter time to POC, and they are spread out on the lower band of the sample range.

(2) The distance to POC distribution is very wide. However, there is a cluster of targets at a range of mostly 20-50 at t = -2, and 30-60 at t = -3, and 40-70 at t = -4. This cluster displays a trend of decreasing time to POC and distance to POC.

(3) In the range of 0-30 meters, the sloping trend no longer exists as target trajectories diversify.

6. Conclusion

This paper offers a discussion of traffic characteristics and their effects on driver behaviors in intersection crossing-path turning maneuvers. First, several categories of traffic attributes were hypothesized to be correlated to driver decisions and behaviors. Next, the traffic patterns at three intersections were described by examining the distribution of vehicle speed and position in the primary direction of opposing traffic facing the turning subject vehicle. Subsequently, the arrival of opposing vehicles as the subject vehicle movies toward the conflict location is analyzed to provide insight into the probable time gap acceptance and high-risk situations. Finally, particular situations when the trailing buffer is short are compared to other situations.

The techniques of data analysis explained in this paper can be used for several purposes. The utilization of data from field observation offers a realistic database for estimating gap acceptance in left-turn across-path scenarios by a population of drivers. The results from the study will allow further understanding of driver risk-taking behaviors in specific maneuvers. Furthermore, the interpretation of such behaviors can serve as the basis for evaluating potential driver perception and acceptance if a warning is issued under similar situations. Moreover, if significant numbers of samples are taken from a diverse set of intersection with unique traffic attributes, the guidelines for adjusting warning criteria can then be systematically established.

An extended effort of field observation should continue to be pursued in the upcoming efforts during the CICAS project. Additionally, at the completion of prototype developments, field operational studies will be conducted to observe the soundness and feasibility of proposed safety solutions. The collection and analysis of additional field data are important topics of future studies.

Acknowledgment

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References

[1] Fuerstenberg, K.C., "Intersection Driver Assistance System - The EC project INTERSAFE," 13th World Congress & Exhibition on Intelligent Transport Systems, London, United Kingdom, October 2006.

[2] Schulze, M., "PReVENT: Prevention and Active Safety Application to Improve Traffic Safety," IEEE Intelligent Vehicles Symposium, Las Vegas, June 2005.

[3] Oda, T., Tajima, T., "Driving Safety Support System for Senior Society, " *ITS World Congress*, Toronto, Canada, October 1999.

[4] Yamamoto, S., Mizutaru, K., Seto, M. "AICHI DSSS (Driving Safety Support System) Field Verification Test," 13th World Congress & Exhibition on Intelligent Transport Systems, London, United Kingdom, October 2006.

[5] Misener, et al, "Toward a Smarter, Safer Intersection: Application of Intelligent Countermeasures to the Intersection Crash Problem," *ITS World Congress*, Madrid, Spain, Nov. 2003.

[6] Schagrin, M., "Cooperative Intersection Collision Avoidance Systems Initiative, " Presentation at Intelligent Transportation Systems America Annual Meeting, May 2005.

[7] http://www.its.dot.gov/cicas/

[8] http://www.its.dot.gov/vii/

[9] http://www.cvisproject.org/

[10] http://www.utms.or.jp/japanese/system/dsss.html

[11] Alexander, L., Cheng, P-M., Donath, M., Gorjestani, A., Menon, A., Newstrom, B, Shankwitz, C., Ward, N., Starr, R., "Rural Expressway Intersection Surveillance for an Intersection Decision Support System," *2006 TRB Annual Meeting*, Paper (06-2795), January 2006.

[12] Staplin L. Simulator and Field Measures of Driver Age Differences in Left-Turn Gap Judgments. *Transportation Research Record No.1485 49-55*, 1995.

[13] Alexander J., Barham P., and Black I. Factors Influencing the Probability of an Incident at a Junction: Results from an Interactive Driving Simulator. *Accident Analysis and Prevention 34 779-792*, 2002.

[14] Chan, C-Y, et al., "Observations of Driver Time-Gap Acceptance at Intersections in Left-Turn Across-Path Opposite-Direction Scenarios," TRB Transportation Records, No. 1910, pp. 10-19.

[15] C-Y. Chan, "Characterization of Driving Behaviors Based on Field Observation of Intersection Left-Turn Across-Path Scenarios," *IEEE Transactions on Intelligent Transportation Systems*, Vol. 7, No. 3, Sept. 2006, pp. 322-331.

[16] Chan, C-Y et al, "California Intersection Decision Support: A Systems Approach to Achieve Nationally Interoperable Solutions," *California PATH Research Report*, UCB-ITS-PRR-2005-11, April 2005.